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Original Article

Suitable habitat prediction with a huge set of variables on some Central Asian tulips

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ABSTRACT

Tulipa (Liliaceae) is cultivated as an ornamental plant worldwide and its wild representatives hold valuable genetic resources for breeders are facing the effects of climate change in Central Asia like all of wild plant species. Therefore, the effects of climate change on two Central Asian species (*T. korolkowii* Regel and *T. lehmanniana* Mercklin) plus the current suitable habitat for two endemics (*T. intermedia* Tojibaev and J.J. de Groot, *T. scharipovii* Tojibaev) to Uzbekistan and one endemic (*T. ferganica* Vved.) to Ferghana Valley were investigated in the study. Because endemic species are valuable for any territory, we cannot trust a limited number of variables that are commonly used for modeling distribution of species. For that, 41 bioclimatic and ecologic variables were utilized in the investigation. The results showed that *T. lehmanniana* is a species most affected by climate change, while *T. korolkowii* appears low necessity for its conservation action. *Tulipa ferganica* mainly grows in some protected areas of Kyrgyzstan which cannot provide protection against climate change and this may help to mitigate its extinction caused by human-driven disturbance. Thus, the conservation implications of these results are discussed.
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Introduction

Conservation of plants is a long-term process that requires sufficient knowledge of the size and dynamics population, the impact of ecological factors, geographic range, and so on. However, traditional conservation prioritization is often based on three criteria: benefit, cost, and likelihood of success, with extinction risk or 'threat category' as a surrogate for the possible benefit that can be derived from conservation activities (Bottrill et al. 2008). Many species have still not been subjected to the global International Union for Conservation of Nature (IUCN) Red List of threatened species, which is typically due to a lack of data to back up the reports (Rodrigues et al. 2006). As an alternative, country-level national Red Lists of plants are more substantial and can provide comprehensive evidence to better assess the precise status of species rather than global ones (Tojibaev and Beshko 2014; Wilson et al. 2021). However, Red listings do not give further information on the extinction or survival of species as it does not include ENM (ecological niche modeling). ENM presents a strategy for making strides to understand the appropriate living space requirements of a species (Phillips et al. 2017). It is crucial for increasing knowledge of extinction risk and deciding on population monitoring, management, and related policies, especially across the Central Asian countries. Plants should be given top priority in conservation efforts due to their critical role in ecosystems of the earth (Ellstrand and Elam 1993).

Tulips are perennial geophytic monocots with ornamental value worldwide. Their cultivation supports an industry valued at more than one billion Euros annually (Christenhusz et al. 2013). The exact number of species of tulip is controversial, varying from about 50 to 100 (Van Raamsdonk and De Vries 1992, 1995; Zonneveld 2009; Christenhusz et al. 2013; Everett et al. 2013; Dekhkonov et al. 2022).

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One of the main causes of this complication may be the extensive historical and horticultural exchange, which has complicated the scientific classification of the genus (Christenhusz et al. 2013). Wild tulips are native to temperate regions of the northern hemisphere (Wilson et al. 2021), specifically to the mountains of Central Asia, which is the main center of diversity (Botschantzeva 1962) and endemism (Tojibaev et al. 2020).

Most tulips inhabit the lower and middle elevations of mountain belts (Botschantzeva 1962). These locales are believed to be incredibly susceptible to climate change (Rangwala and Miller 2012). Plants in these regions may be especially sensitive to this threat (Nowak et al. 2020). Nevertheless, the lower semi-desert and steppe areas of Central Asia, where fewer species of tulips grow, are also reportedly fragile in a changing climate with numerous areas prognosticated to becoming increasing thirsty over time (Huang et al. 2020).

Vernalization, common in bulbous plants, depends on cold temperature as a trigger for the initial growth of bulbs (Wilson et al. 2021). The seeds of tulips need a particular period cold to germinate, while their body mass variation is correlated with day length (Growing deg days) (Botschantzeva 1962). Also, tulips require dry soil. Dampness may result in rot and other diseases as well (Everett et al. 2013). Thus, the annual or quarterly amount of rainfall may be the main factor for the growth of tulips.

ENMs are empirical methods that relate data from field observations to environmental predictor variables based on a combination of statistically or theoretically derived response curves that best reflect the ensemble of ecological requirements of a species (Guisan and Thuiller 2005). The ecology and distribution of terrestrial plant species are influenced by climatic conditions, which are critical for physiological function and survival in plants (Becklin et al. 2016). Therefore, the most important agents in determining the distribution of vegetation should be addressed (Juffe-Bignoli et al. 2014; Tshwene-Mauchaza and Aguirre-Gutiérrez 2019). Modeling of niches of species under a current and changing climate requires spatially explicit environmental predictors. The widely used Bioclimatic and recently introduced Envirem predictors in niche modeling are valuable datasets for ENM for a variety of applications (Title and Bemmels 2018). Creating ENM for rare and poorly known species can be a difficult task. However, researchers are often most interested in building ENM for rare species, as they are often the most threatened and in the greatest need of conservation action (Breiner et al. 2015).

Tulipa lehmanniana and *Tulipa korolkowii* are ranked as category vulnerable (VU) and endangered (EN) in the National Red (Data) books of central Asian countries (Red Data Book of Kyrgyz Republic 2006; Khisoriev 2017; Khassanov 2019). In the Red Data Book of Uzbekistan (Khassanov 2019), which still uses the outdated rarity status system, *T. lehmanniana* and *T. korolkowii* are categorized as decreasing in number (category 3) and unique (category 2), respectively. *Tulipa ferganica* Vved. is also included in the national Red Data Book of Uzbekistan under category 2; however, our field conclusions revealed that population sizes are gradually decreasing year by year (unpublished data). Another two endemic species of Uzbekistan, *Tulipa scharipovii* and *Tulipa intermedia* with a restricted number of local populations in the Ferghana Valley, maybe the real victims of high anthropogenic impact and climate change (Dekhkonov et al. 2021).

In this study, first, it is planned to determine the most important ecological niches of tulips in Central Asia within a huge number of ecologic and climatic variables. For this purpose, we have selected two widespread Tulipa species within Central Asia that grow in deserts and semi-deserts. Plus, two endemic species from Uzbekistan and one species from Fergana Valley (suffering from anthropogenic actions) were selected. Second, it was attempted to determine the responses to climate change for two of them (*T. korolkowii* and *T. lehmanniana*). Third, it was tried to determine areas that may be potentially suitable for possible conservation efforts for the rare species (*T. ferganica, T. intermediata* and *T. scharipovii*). Taxonomic treatment for surveyed species was followed by Tojibaev et al. (2022). Based on our findings, the ecological niches of each of the species are characterized and attempted to predict the potential suitable areas and make suggestions about possible conservation actions. This study was original in terms of the number of variables used in the niche studies of the species of *Tulipa*.

Material and methods

Study area

Central Asia is located on the internal side of the Eurasian continent with 9950 km long and 8650 km wide. It stretches from the Caspian Sea in the west to China and Mongolia including 5 countries: Kazakhstan, Uzbekistan, Tajikistan, Turkmenistan, and Kyrgyzstan with 4 003 451 km^2 total area. The lowest and highest points range from −154 m to 7495 m (Jelen et al. 2020). It extends between 45–90 E and 36–55 N. The western edge of the territory is bordered by Kigach river (Kazakstan, 46.659387 N, 48.489676 E), the western part of Shungai village (Kazakstan, 48.432968 N, 46.493986 E), and vicinities of Esenguli city (Turkmenistan, 37.420414 N, 53.959249 E). Northern edges end with Isakovka village (Kazakstan, 55.441028 N, 68.933325 E) and Uy river (Kazakstan, 54.078678 N, 61.330293 E). Eastern edge of the study area is bordered by Belukha mountains (Kazakstan, 49.804804 N, 86.598423 E). The south part of the area is bordered by Serxetabad city (Turkmenistan, 35.251473 N, 62.341880 E) and Ishkoshim village (Tajikistan, 36.701102 N, 71.712202 E). All geographic names and coordinations are produced by Google Earth Pro 7.3.4.8248 (server kh.google.com).

Central Asia is a particularly vulnerable region due to its physical geography with temperate deserts and semi-deserts (Lioubimtseva and Henebry 2009). The environment is very sensitive to global climate change, and it is particularly vulnerable to changing weather patterns (Brooke 2014). Especially, water resources in this area are the main factors for the sustainable development of biodiversity. There is a low concentration of water vapor over this area and the distribution of water resources in Central Asia is very uneven. Despite the critical habitat for biodiversity, it is considered one of the main centers of plant diversity (Nowak et al. 2020) and endemism in particular (Tojibaev et al. 2020), which represents nearly 10 thousand species of vascular plants (Khassanov 2015).

Ecological niches and climate change modeling

Data collection

The distribution of the species of *Tulipa* was collected using a Global Positioning System in Uzbekistan, Kyrgyzstan, and Kazakhstan and from points available on the Global Biodiversity Information Facility website (GBIF 2022). We thinned records using the 'enmSdm' R package and Central Asia elevation data (obtained from SRTM data in 30 arcsec) to mitigate errors (Morelli et al. 2020). Ultimately, 129 records for *T. korolkowii*, 89 for *T. lehmanniana*, 29 for *T. ferganica*, 11 for *T. scharipovii*, and 13 for *T. intermedia* were obtained to build the ENMs of the species.

Preparing and choosing predictor variables

Bioclimatic variables used in this study were obtained from the Worldclim website (Fick and Hijmans 2017) and were cropped and reduced to the size that comprises all of Central Asia. Environmental variables, which we believed to be complementary of the Bioclimatic data, were created using temperature minimum,

maximum, and precipitation data again downloaded from Worldclim using Envirem R package (Title and Bemmels 2018). All variables downloaded, created, and edited for this study were in 30 arcsec resolution and can be seen in Appendices A and B.

Correlation analysis between variable pairs was performed with Spearman correlation analysis using 'SDMtune' R package on all 41 variables (R Core Team 2020; Vignali et al. 2020). Variable importance was revealed using four R packages which had features on variable selection steps in the modeling pre-processing stages. The libraries used in this stage were 'SDMtune' (for variable selection via cross-validated Maximum Entropy modeling) (Vignali et al. 2020), 'Embarcadero' (for variable selection based on trees generated via BART algorithm) (Carlson 2020), 'Ecospat' (for analyzing Variance Inflation Factor among variables) (Di Cola et al. 2017). Based on the predictions from the R libraries used and correlations between variable pairs, we identified various number sets of variables that might be effective in the current distribution of each species. Then 'Ellipsenm' R package (Cobos et al. 2019) was used to evaluate and select the best model according to the criteria where the best model was the one statistically significant, with low omission rates, and low prevalence by calibrating candidate models.

In the end, the variables that were chosen for modeling the species ecological niches were bio06, bio015, bio19, continentality, and PETSeasonality for *T. lehmanniana*; bio06, bio015, bio19, bio04, and PETSeasonality for *T. korolkowii*; bio03, bio015, and climaticMoistureIndex for *T. ferganica*; PETWettestQuarter and bio19 for *T. intermedia*; bio15 and PetColdestQuarter for *T. sharipovii*. All variables that were predicted to be included in the species ENMs by each R library can be seen in Appendix C.

Modeling the species niches and future suitable distribution areas

Maximum Entrophy is the most prominent and widely used ENM technique in scientific research (Fitzpatrick et al. 2013; Fourcade et al. 2014). It can be implemented in a variety of packages in R including 'dismo' Hijmans et al. (2017), 'SDMtune' (Vignali et al. 2020), and 'enmSdm' (Elith et al. 2006; Phillips et al. 2006; Morelli et al. 2020). In the model processing stage, we used the SDMtune (Vignali et al. 2020) for ENMs of *T. ferganica, T. intermedia*, and *T. scharipovii* and enmSdm for ENM and Climate Change Modeling of *T. lehmanniana* and *T. korolkowii*. Both packages have the main objective is to put together all methodological diversity developed within the ENM field and represent a new, unified, and user-friendly framework for the still-growing field of ENM (Morelli et al. 2020; Vignali et al. 2020). Moreover, these new packages offer lots of frameworks to build and systematically tune ENMs to be able to get models with more predictive power. In building ENMs and CCMs of all species of tulips, we followed the tutorials supplied by developers of R library developers (see http://www.earthskysea.org/best-practices-in-species-distribution-modeling-a-workshop-in-r/ and https://consbiol-unibern.github.io/SDMtune/).

In niche modeling of the tulips with fewer records since algorithms' performance may be sensible to the way pseudo-absences

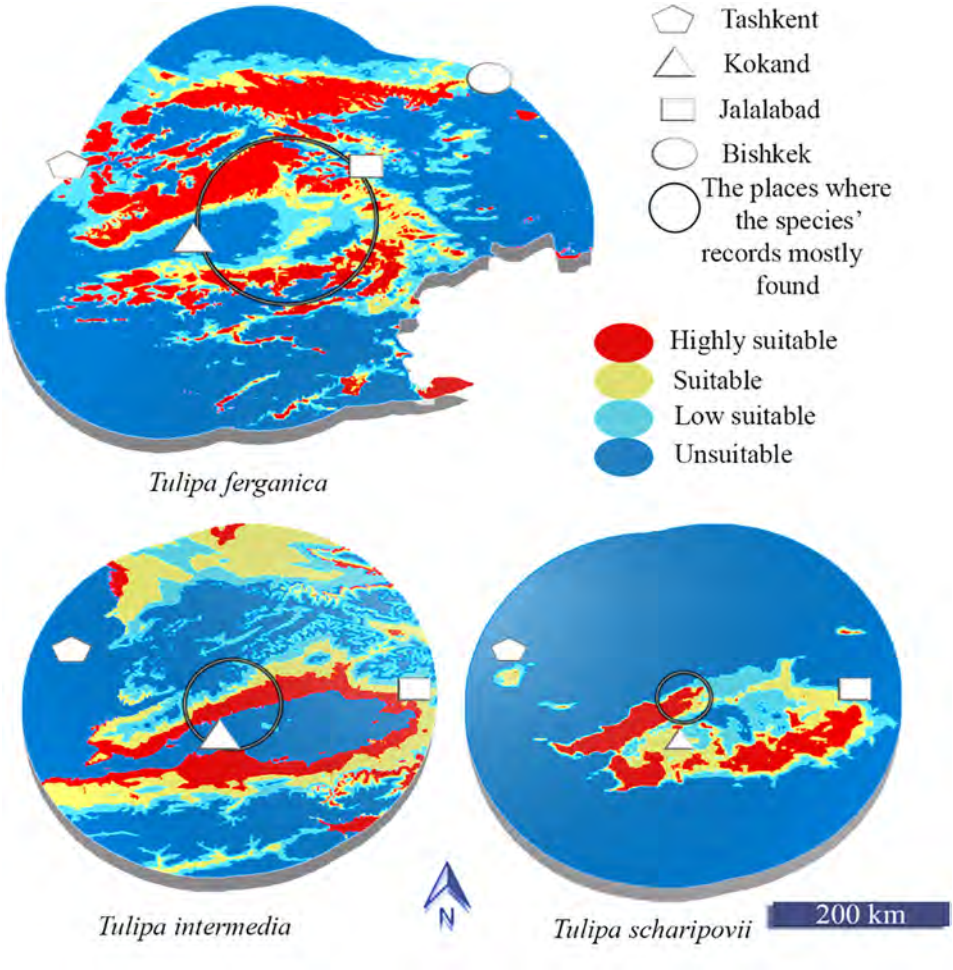


Figure 1. Current ENMs of the three species of tulips. ENM, ecological niche modeling.

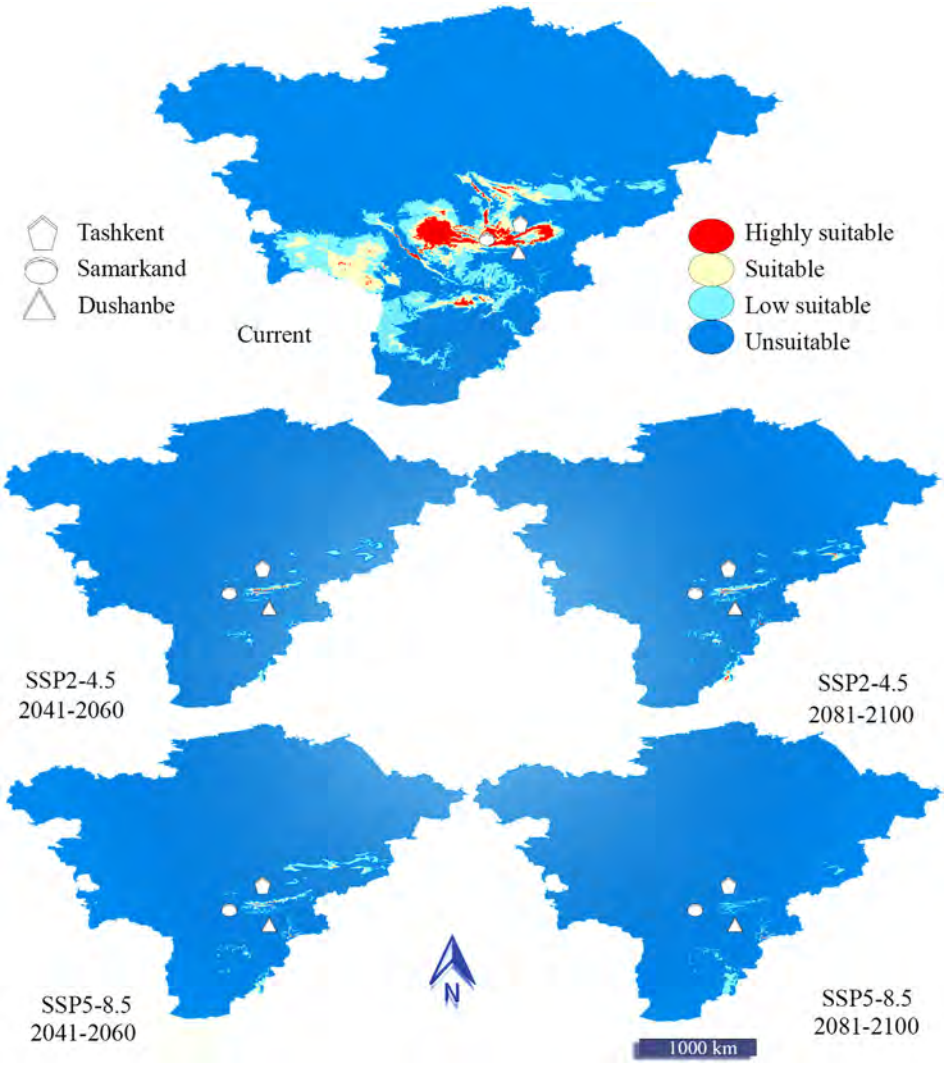


Figure 2. Current ENM and future CCMs of the *T. lehmanniana*. ENM, ecological niche modeling.

are distributed throughout the calibration area (Barbet-Massin et al. 2012), it was buffered 200 km radius zone areas around of every record based on the knowledge of species ecology, dispersal ability, and geographical barriers for three species of tulips. Then we had cross-validated niche models using SDMtune. Then we had four cross-validated niche models using SDMTune. In the end using 'Grid-Search" function, model hyperparameters of cross-validated models were tuned (Vignali et al. 2020).

In the ENMs and CCMs of *T. lehmanniana* and *T. korolkowii* because of enough records (greater than 50), we projected the models for all Central Asia region. Since the results of CCMs are affected by a range of factors, including the choice of global circulation models range and emission scenarios (Porfirio et al. 2014; Sari and Kandemir 2020; Ullah et al. 2022) Beijing Climate Center Climate System Model (BCCCSM) global circulation models (Beijing Climate Center, Climate System Model), which has higher reliability and has been better studied for the areas the species live, was chosen to use in CCMs of the *T. lehmanniana* (Wu et al. 2018) (Coupled Model Intercomparison Project, CMIP6 2022). The scenarios used were the Shared Socioeconomic Pathways (SSPs, SSP2-4.5, and SSP5-8.5) (CMIP6), which are now being used as important inputs for the latest climate models, feeding into the Intergovernmental Panel on Climate Change (IPCC) sixth assessment report (Ara Begum et al. 2022). All in all, CCMs of the species were predicted for 20-year periods (2041–2060 and 2081–2100). The R package used here was enmSdm (SDMtune has no feature on projecting models for different times and regions).

Model evaluation and creating suitability maps

In model evaluation, AUC and TSS in all ENMs and CCMs of the species were used. Thresholds for interpreting the metric values were defined as follows: Value $\geq$ 0.9 = best, 0.9 > Value $\geq$ 0.8 = very good, 0.8 > Value $\geq$ 0.7 = good, and Value < 0.7 = weak (Allouche et al. 2006; Leroy et al. 2018).

Four threshold values used in creating niche maps of the species. Accordingly, '0–0.25' denotes unsuitable areas, '0.25–0.5' areas of low suitability, '0.5–0.75' areas of moderate suitability, and '0.75–1' highly suitable areas.

Finally, to be able to see to what extent the areas which were predicted to be suitable (mid-highly suitable areas) for *T. korolkowii* and *T. lehmanniana* overlap with protected areas of Central Asia 'reclassify' and 'raster calculator' functions built in 'Spatial Analyst Tool' in ArcMap 10.8 (ESRI 2022) were used. Protected areas data were obtained from Protected Planet (UNEP-WCMC and IUCN 2022).

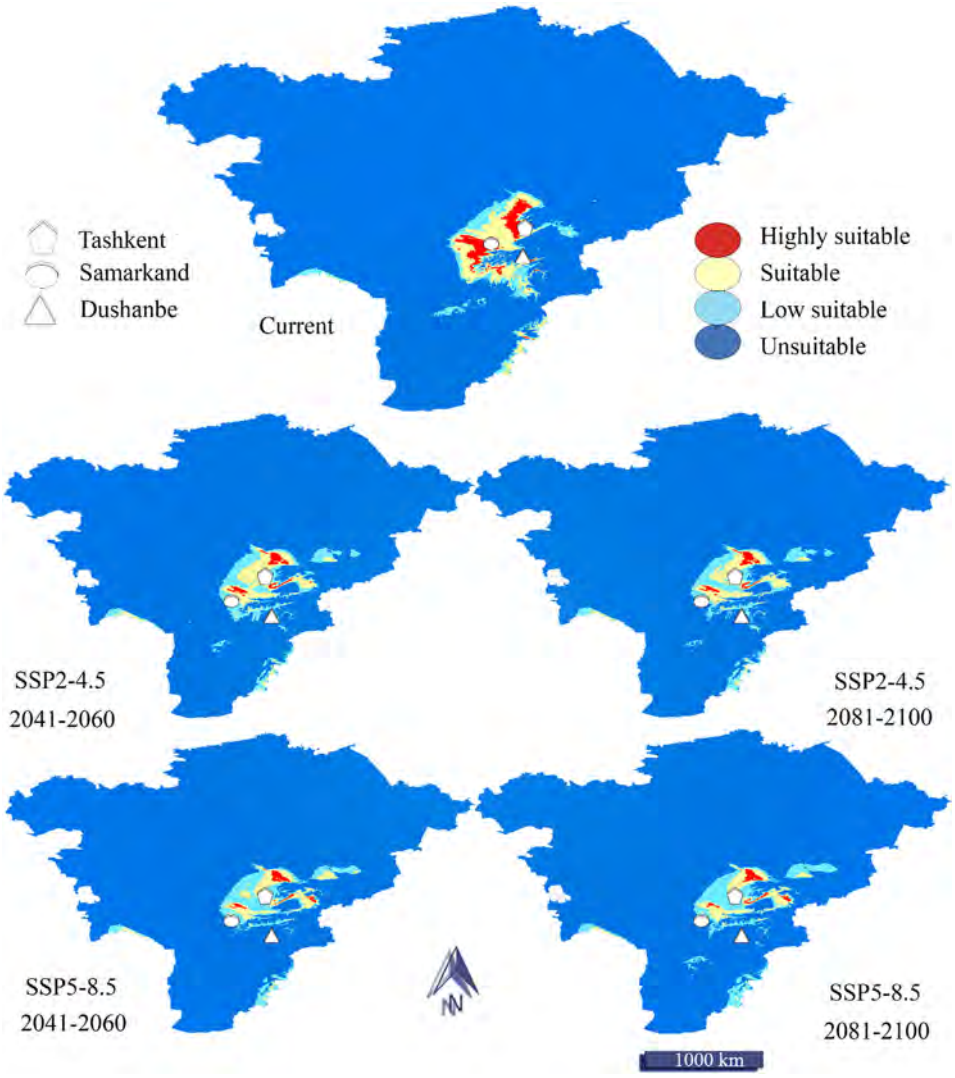


Figure 3. Current ENM and future CCMs of the *T. korolkowii*. ENM, ecological niche modeling.

Table 1. The size of unsuitable-highly suitable areas predicted by the current and future niche models for *T. lehmanniana* (Tl) and *T. korolkowii* (Tk) in km^2.

	Current Tl–Tk	SSP 2.45 2041–2060 Tl–Tk	SSP 2.45 2081–2100 Tl–Tk	SSP 5.85 2041–2060 Tl–Tk	SSP 5.85 2081–2100 Tl–Tk
Unsuitable	6.511.702–7.181.151	7.502.625–7.081.075	7.470.625–7.114.075	7.465.900–7.121.875	7.525.625–7.105.200
Low suitable	625.676–153.104	60.450–270.725	81.300–262.725	93.000–280.325	47.400–309.550
Suitable	315.940–180.539	10.075–197.075	19.150–174.950	15.250–151.275	1.775–138.225
Highly suitable	121.469–59.993	1.975–26.250	4.050–23.375	975–21.650	325–2.2150

Results

ENMs of the species

Looking at the current suitable distribution areas predicted by the models and the areas where the species individuals mostly found, it can be easily realized that the areas predicted to be suitable for the species *T. ferganica, T. intermedia*, and *T. scharipovii* are located very close to their current habitats (Figure 1).

While current and future ecological niche distribution areas can be seen in Figures 2 and 3, the size of unsuitable-highly suitable areas for the current and future time periods for the niches of *T. lehmanniana* and *T. korolkowii* niches can be seen in Table 1 and Figure 4.

While considering the bar charts, it can be easily realized that there are huge differences in size in low suitable-highly suitable areas for the species. Although the areas predicted to be suitable for the future in both species have decreased compared to the present, it is clear that the biggest loser is *T. lehmanniana*.

The most important environmental predictors for *T. lehmanniana* and *T. korolkowii* were almost similar excluding continentality of the climate and temperature seasonality of a year (Table 2). Bioclimatic variables for the remaining three species varied to some extent but all were linked to precipitation and moisture of the climate. Climatic moisture, isothermality, and precipitation seasonality for *T. ferganica*, potential evapotranspiration of wettest quarter and precipitation of coldest quarter for *T. intermedia*, potential evapotranspiration of coldest quarter and precipitation

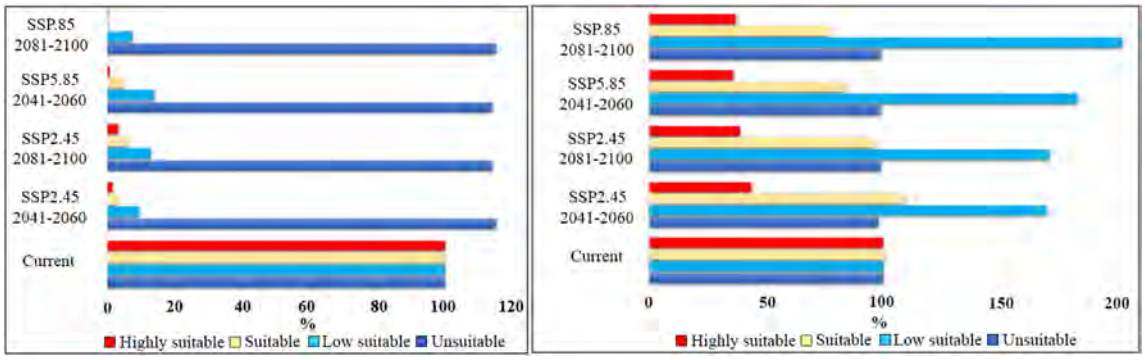


Figure 4. Bar chart comparing the percentage of the habitat suitability in relation to the current suitable habitats across 2041–2060 and 2081–2100 for *T. lehmanniana* (left) and *T. korolkowii* (right) under climate modelling.

Table 2. The most important climatic variables for SDM.

T. lehmanniana	*T. korolkowii*	*T. ferganica*	*T. intermedia*	*T. sharpovii*
Bio06	Bio04	Bio03	Bio15	Bio15
Bio15	Bio06	Bio015	Bio19	PET Coldest Quarter
Bio19	Bio15	Climatic Moisture Index	PET Wettest Quarter	
Continentality	Bio19			
PET Seasonality	PET Seasonality			

Response curves to predictor variables and AUC and TSS values of the Maxent models of species of tulips and variable importance of all ENMs can be seen in Appendix D-J.

seasonality for *T. scharipovii* had great impact on species niches. Models broadly highlighted Tian Shan mountains as most suitable habitat for *T. korolkowii, T. ferganica, T. intermedia*, and *T. scharipovii*.

Overlap with the protected areas of Central Asia

According to the ENM and CCM prediction maps, we obtained and protected areas map of Central Asia, the areas that are predicted to be suitable (moderate and highly suitable areas) for *T. korolkowii* and *T. lehmanniana* both in the current and in the future almost do not overlap (less than %1 for current and any for future) with the protected areas (Figure 5).

Discussion

Because the predictions obtained from the ecological niche models are strongly dependent on the variables used (Porfirio et al. 2014), and endemic species are among of the world's most important biological heritage, we did not want to depend on only a limited number of predictive variables as is common in many modeling studies. In particular, the inclusion of some Envirem variables as well as bioclimatic variables (Title and Bemmels 2018) in our models and their detection by more than one method, we implemented may contribute positively (see Appendices A and B) to possible conservation studies to be planned in the future.

The suggestion of Envirem variables such as PETseasonality, PETColdestQuarter, and PETDriestQuarter by different methods for more than one species of tulips in the variable selection procedures, we applied strengthens the possibility that these variables may have a role in determining the niche of species of tulips. Future investigations in niche modeling on species of tulips with more location data (especially more than 50) (Guisan et al. 2017) will shed more light on this issue.

Species distribution across the study area and main recommendations

The habitat of *T. lehmanniana* is generally sandy or stony ground between rocky outcrops. The main range of the species includes the Kyzylkum desert in Kazakhstan and Uzbekistan (Wilford and Zarrei 2009; Tojibaev and Beshko 2014). Particularly, Kuldzhuktau, Tamdytau, Kazakhtau, and Tokhtatau other remnant mountains located in the Kyzylkum desert are the locations for the populations in Uzbekistan (Shomurodov et al. 2021). Accordingly, the height and mass of *T. lehmanniana* vary considerably between high moisture regions and low moisture regions. This shed lights that moisture or precipitation are the main ecologic requirements for *T. lehmanniana*, as in other desert plants. In addition, desert ecosystems are predicted to be among the most vulnerable ecosystems of global climate change (Sala et al. 2000; Loarie et al. 2009). The predictions from the CCM of species of tulips with sufficient

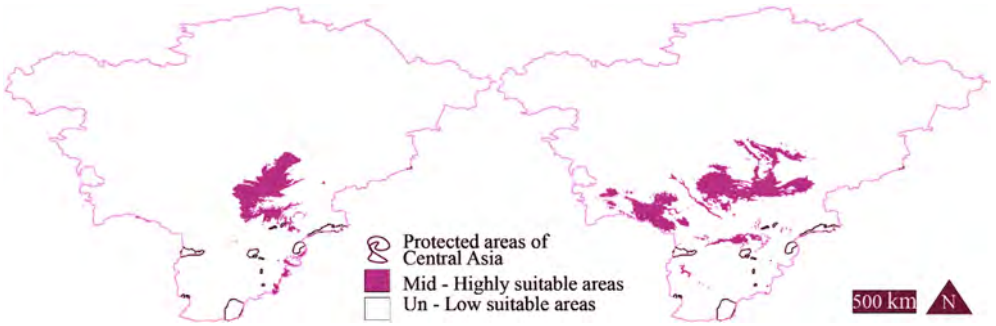


Figure 5. The minimal overlap of moderate and highly suitable areas predicted by ENMs of *T. korolkowii* (left) and *T. lehmanniana* (right) with the Central Asia's protected areas. ENM, ecological niche modeling.

location data (*T. lehmanniana*) recommended that urgent conservation measures for *T. lehmanniana* should be taken. However, we do not claim with strong confidence that the prediction is highly probable, but we offer conservationists to measure population dynamics permanently.

More likely, *T. korolkowii* spreads over semi-desert and middle mountains and grows at relatively higher elevations (500–1500 m a.s.l.). This species occurs in Uzbekistan (mostly foothills and low mountain belts of the Pamir-Alay ranges of Fergana Valley), Kazakhstan (southern parts), and Kyrgyzstan (Fergana Valley) (Wilford 2007; Abduraimov et al. 2020a, b). When both our and the study by Wilson et al. (2021) about *T. korolkowii* were considered, no conservation actions for this species are needed for new, except for the restricted representation of this taxon in protected areas. *Tulipa korolkowiii* grows well when annual precipitation is high. Therefore, if any ecological danger like global warming affects its habitat, it can be translocated to any habitat with a high rate of precipitation and above about 800 m a.s.l.

Tulipa ferganica grows in Ferghana valley across the borders of Uzbekistan and Kyrgyzstan (Tojibaev et al. 2018). Due to obtained records, we reframed us to model a future suitable habitat for *T. ferganica.* However, it is a fact from our expedition that this species is one of the most threatened species of tulips due to land use and overgrazing (Dekhkonov et al. 2021). Thus, suitable habitats for this species were predicted in advance, in case of preventing any extinction risk in its natural habitat. Two species, *T. intermedia* and *T. scharipovii*, which are endemics to Uzbekistan (Dekhkonov et al. 2021), grow in a restricted number of populations (5 or 6 populations). Particularly, populations of *T. intermedia* cover only 30–35 km^2 in their natural habitat (Tojibaev et al. 2014). This species is distributed in under special conditions, but it can quickly disappear and require serious control (Khassanov 2019). In our ENMs, suitable habitats highlighted for *T. intermedia* were mainly in the Pamir-Alay ranges at about 700–1200 m a.s.l which surrounds three regions of Uzbekistan (Namangan, Fergana, Andijan) and the lower belt of Kurama range. *Tulipa scharipovii,* endemic species to Ferghana valley, mainly spreads across the foothills and piedmont zone of Kurama range from Turakurgan district to Rezaksay (Namangan, Uzbekistan). It grows in foothills with loess and saline soils with single individuals or small groups. Each population consists of 40–50 individuals in 100 m^2 (unpublished data). The extreme limiting factors for the species are high pressure of anthropogenic impact including fragmentation and overgrazing. Suitable habitats for this species out of its current habitat (Uygursay, Charkesar, Chadak, Olmos) can be Kyzyl-kiya, Aravan, and Alashan of Kyrgyzstan part alongside border of Andijan and Fergana regions at about 600–1100 m a.s.l.

Conclusion

In our study, we both utilized a different number (41 variables) of bioclimatic and ecologic variables as well as variable selection procedures implemented in ENM studies of species of tulips for the first time. Moreover, despite the limited number of records we had, by taking advantage of recently introduced R ecological libraries on modeling the ecological niches of species, we revealed that especially 'Continentality,' 'PETSeasonality,' 'Climatic Moisture Index,' 'PETWettestQuarter,' and 'PETColdestQuarter' Envirem variables that are rarely used in modeling studies are important predictor variables for tulips. We recommend using rarely used, recently introduced and/or updated methods that are available in different R libraries if you are eager to know about ecological drivers that could be effective in determining ecological niches (see Appendices A and B).

The main suitable habitat for *T. lehmanniana* was decreased hugely in the model, but it may be just machine speculation. However, *T. lehmanniana* needs to be surveyed further in comprehensive detail, including its genetic diversity, adaptability, and population dynamics. The results for *T. lehmanniana* and other desert species may urge ecologists to take serious action to determine whether desert species can adapt to climate change or go extinct.

Endemic species (*T. intermedia* and *T. scharipovii*) can go extinct as the result of anthropogenic impacts (i.e. pasturing, picking, fragmentation, land use, and etc.) due to their constrained population size. Assessing suitable habitat in a particular territory (i.e. protected area) would conserve them from the above-mentioned dangers.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.japb.2022.10.007.

References

Abduraimov OS, Shomurodov HF, Daniyarov SA, et al. 2020a. Distribution and current state of rare and endangered tulips (Liliaceae) in Arid Zones of Uzbekistan. *American Journal of Plant Sciences* 11:736–744.

Abduraimov O, Shomurodov H, Daniyarov S, et al. 2020b. Ontogenetic structure of ceonopopulations of *Tulipa korolkowii* Regel in Uzbekistan. *Journal of Botanical Research* 2:7–11.

Allouche O, Tsoar A, Kadmon R. 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). *Journal of Applied Ecology* 43:1223–1232.

Ara Begum R, Lemper EA, Benjaminsen TA, et al. 2022. Point of departure and key concepts. In: Pörtner HO, Roberts DC, Tignor M, et al., editors. *Climate change 2022: Impacts, adaptation, and vulnerability. Contribution of working group II to the Sixth assessment report of the intergovernmental panel on climate change.* Cambridge, UK and New York, USA: Cambridge University Press. pp 121–196. https://doi.org/10.1017/9781009325844.003.

Barbet-Massin M, Jiguet F, Albert CH, et al. 2012. Selecting pseudo-absences for species distribution models: how, where and how many? *Methods in Ecology and Evolution* 3:327–338.

Becklin KM, Anderson JT, Gerhart LM, et al. 2016. Examining plant physiological responses to climate change through an evolutionary lens. *Plant Physiology* 172: 635–649.

Botschantzeva Z. 1962. *Tulips. Taxonomy, morphology, cytology, phytogeography and physiology.* Russian edn. Rotterdam: Balkema.

Bottrill MC, Joseph LN, Carwardine J, et al. 2008. Is conservation triage just smart decision making? *Trends in Ecology and Evolution* 23:649–654.

Breiner F, Guisan A, Bergamini A, et al. 2015. Overcoming limitations of modelling rare species by using ensembles of small models. *Methods in Ecology* 6:1210–1218.

Brooke J. 2014. *Climate change and the course of global history: A rough journey.* Cambridge: University Press.

Carlson C. 2020. Embarcadero: Species distribution modelling with Bayesian additive regression trees in R. *Methods in Ecology and Evolution* 11:850–858.

Christenhusz MJ, Govaerts R, David JC, et al. 2013. Tiptoe through the tulips–cultural history, molecular phylogenetics and classification of Tulipa (Liliaceae). *Botanical Journal of the Linnean Society* 172:280–328.

Cobos M, Osorio-Olvera L, Soberon J. 2019. *Ellipsenm: an R package for ecological niche's characterization using ellipsoids*. Version R package version 0.3.4, https://github.com/marlonecobos/ellipsenm. [Date accessed: 27 October 2020].
Dekhkonov D, Tojibaev K, Makhmudjanov D, et al. 2021. Mapping and analyzing the distribution of the species in the genus *Tulipa* (Liliaceae) in the Ferghana Valley of Central Asia. *Korean Journal of Plant Taxonomy* 51:181–191.
Dekhkonov D, Tojibaev K, Yusupov Z, et al. 2022. Morphology of tulips (*Tulipa*, Liliaceae) in its primary centre of diversity. *Plant Diversity of Central Asia* 1:52–70.
Di Cola V, Broennimann O, Petitpierre B, et al. 2017. ecospat: an R package to support spatial analyses and modeling of species niches and distributions. *Ecography* 40:774–787.
Elith J, Graham C, Anderson R, et al. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29:129–151.
Ellstrand NC, Elam DR. 1993. Population genetic consequences of small population size: implications for plant conservation. *Annual Review of Ecology, Evolution and Systematics* 24:217–242.
Environmental Systems Research Institute (ESRI). 2014. *ArcGIS desktop help 10.2 geostatistical analyst*. Available at: http://resources.arcgis.com/en/help/main/10.2/index.html. [Date accessed: 4 March 2014].
Everett D, Fay MF, Christenhusz M, et al. 2013. *The genus Tulipa: tulips of the world*. Kew, London: Kew Publishing.
Fick SE, Hijmans RJ. 2017. WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology* 37:4302–4315.
Fitzpatrick M, Gotelli N, Ellison A. 2013. MaxEnt versus MaxLike: empirical comparisons with ant species distributions. *Ecosphere* 4:1–15.
Fourcade Y, Engler J, Rödder D, et al. 2014. Mapping species distributions with MAXENT using a geographically biased sample of presence data: a performance assessment of methods for correcting sampling bias. *PLoS One* 9:e97122.
GBIF. 2022. Available at: https://doi.org/10.15468/dl.ucfhd2 [Data accessed: 01 October 2022].
Guisan A, Thuiller W. 2005. Predicting species distribution: offering more than simple habitat models. *Ecology Letters* 8:993–1009.
Guisan A, Thuiller W, Zimmermann N. 2017. *Habitat suitability and distribution models: with applications in R*. Cambridge: Cambridge University Press.
Hijmans RJ, Phillips S, Leathwick J, et al. 2017. Package 'dismo'. *Circles* 9:1–68.
Huang J, Zhang G, Zhang Y, et al. 2020. Global desertification vulnerability to climate change and human activities. *Land Degradation and Development* 31:1380–1391.
Jelen I, Angelija B, Francesco Ch, et al. 2020. *The geography of Central Asia*. Switzerland: Springer Cham. https://doi.org/10.1007/978-3-030-61266-5.
Juffe-Bignoli D, Burgess ND, Bingham H, et al. 2014. *Protected planet report 2014*. Cambridge: UNEP-World Conservation Monitoring Centre.
Khassanov F. 2015. *Conspectus Florae Asiae Mediae*, vol. 11. Tashkent: Science Publishers.
Khassanov F. 2019. *The Red Data Book of the Republic of Uzbekistan*. Voulme 1. Plants. Tashkent: Chinor ENK Press.
Khisoriev H. 2017. *The Red Book of the Republic of Tajikistan*, vol. 1. Dushanbe: Ganch press.
Leroy B, Delsol R, Hugueny B, et al. 2018. Without quality presence–absence data, discrimination metrics such as TSS can be misleading measures of model performance. *Journal of Biogeography* 45:1994–2002.
Lioubimtseva E, Henebry G. 2009. Climate and environmental change in arid Central Asia: Impacts, vulnerability, and adaptations. *Journal of Arid Environments* 73:963–977.
Loarie S, Duffy P, Hamilton H, et al. 2009. The velocity of climate change. *Nature* 462:1052–1055.
Morelli T, Smith A, Mancini A, et al. 2020. The fate of Madagascar's rainforest habitat. *Nature Climate Change* 10:89–96.
Nowak A, Świerszcz S, Nowak S, et al. 2020. Red List of vascular plants of Tajikistan–the core area of the Mountains of Central Asia global biodiversity hotspot. *Scientific Reports* 10:1–10.
Phillips S, Anderson R, Schapire R. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190:231–259.
Phillips SJ, Anderson RP, Dudík M, et al. 2017. Opening the black box: An open-source release of Maxent. *Ecography* 40:887–893.
Porfirio L, Harris R, Lefroy E, et al. 2014. Improving the use of species distribution models in conservation planning and management under climate change. *PLoS One* 9:e113749.
R Core Team. 2020. *R: A language and environment for statistical computing. R Foundation for Statistical Computing*. Vienna: Austria. Available at: www.r-project.org. [Date accessed: 14 February 2019].
Rangwala I, Miller J. 2012. Climate change in mountains: a review of elevation-dependent warming and its possible causes. *Climatic Change* 114:527–547.
Rodrigues AS, Pilgrim JD, Lamoreux JF, et al. 2006. The value of the IUCN Red List for conservation. *Trends in Ecology and Evolution* 21:71–76.
Sala O, Stuart Chapin F, Armesto J. 2000. Global biodiversity scenarios for the year 2100. *Science* 287:1770–1774.
Sari I, Kandemir A. 2020. Will Ferulago glareosa Kandemir and Hedge (Apiaceae) be extinct in the near future? *Turkish Journal of Botany* 44:427–440.
Shomurodov K, Abduraimov O, Adilov B. 2021. Assessment of the state of *Tulipa lehmanniana* Mercklin populations under the conditions of the Kyzylkum desert. *Arid Ecosystems* 11:83–90.
Title PO, Bemmels JB. 2018. ENVIREM: an expanded set of bioclimatic and topographic variables increases flexibility and improves performance of ecological niche modeling. *Ecography* 41:291–307.
Tojibaev K, Beshko N. 2014. Reassessment of diversity and analysis of distribution in *Tulipa* (Liliaceae) in Uzbekistan. *Nordic Journal of Botany* 33:324–334.
Tojibaev KS, De Groot J, Naralieva N. 2014. *Tulipa intermedia* sp. nov. (Liliaceae) from the Ferghana Depression, Uzbekistan. *Nordic Journal of Botany* 32:546–550.
Tojibaev KS, Karimov F, Oh B, et al. 2018. A checklist of the geophytes of Fergana Valley, Middle Asia-a monocotyledonous plant and biogeographical analysis. *Journal of Asia-Pacific Biodiversity* 11:431–441.
Tojibaev KS, Jang CG, Lazkov GA, et al. 2020. An annotated checklist of endemic vascular plants of the Tian-Shan Mountains in Central Asian countries. *Phytotaxa* 464 (2):117–158.
Tojibaev KS, Dekhkonov D, Ergashov I, et al. 2022. The synopsis of the genus *Tulipa* (Liliaceae) in Uzbekistan. *Phytotaxa* 573 (2):163–214.
Tshwene-Mauchaza B, Aguirre-Gutiérrez J. 2019. Climatic drivers of plant species distributions across spatial grains in Southern Africa tropical forests. *Frontiers in Forests and Global Change* 2:69.
Ullah F, Gao Y, Sari I, et al. 2022. Macro-Morphological and Ecological Variation in Rosa sericea Complex. *Agronomy* 12:1078.
UNEP-WCMC, IUCN. 2022. *Protected Planet: The World Database on Protected Areas (WDPA). Cambridge*. UK: UNEP-WCMC and IUCN.
Van Raamsdonk L, De Vries T. 1992. Biosystematic studies in *Tulipa* sect. *Eriostemones* (Liliaceae). *Plant Systematics and Evolution* 179:27–41.
Van Raamsdonk L, De Vries T. 1995. Species relationships and taxonomy in *Tulipa* subg. *Tulipa* (Liliaceae). *Plant Systematics and Evolution* 195:13–44.
Vignali S, Barras A, Arlettaz R, et al. 2020. SDMtune: An R package to tune and evaluate species distribution models. *Ecology and Evolution* 10:11488–11506.
Wilford R. 2007. *TULIPA KOROLKOWII*: Liliaceae. *Curtis's Botanical Magazine* 26:217–222.
Wilford R, Zarrei M. 2009. *TULIPA LEHMANNIANA*: Liliaceae. *Curtis's Botanical Magazine* 26:33–42.
Wilson B, Dolotbakov A, Burgess BJ, et al. 2021. Central Asian wild tulip conservation requires a regional approach, especially in the face of climate change. *Biodiversity* 30:1705–1730.
Wu X, Dong S, Liu S, et al. 2018. Identifying priority areas for grassland endangered plant species in the Sanjiangyuan Nature Reserve based on the MaxEnt model. *Biodiversity Science* 26:138–148.
Zonneveld BJ. 2009. The systematic value of nuclear genome size for 'all' species of *Tulipa* L.(Liliaceae). *Plant Systematics and Evolution* 281:217–245.

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